

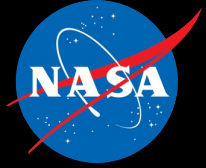


EXPLORE

Alison Park
Députy Tech Fellow – NASA Engineering and Safety Center
AM for Defense, Aerospace, and Space, Orlando | June 13-15, 2023

Additive Manufacturing at NASA

Apollo Generation





Artemis Generation





NASA is moving from Low Earth paradigm to Deep Space paradigm

Additively manufactured parts are already being used for NASA programs in critical applications

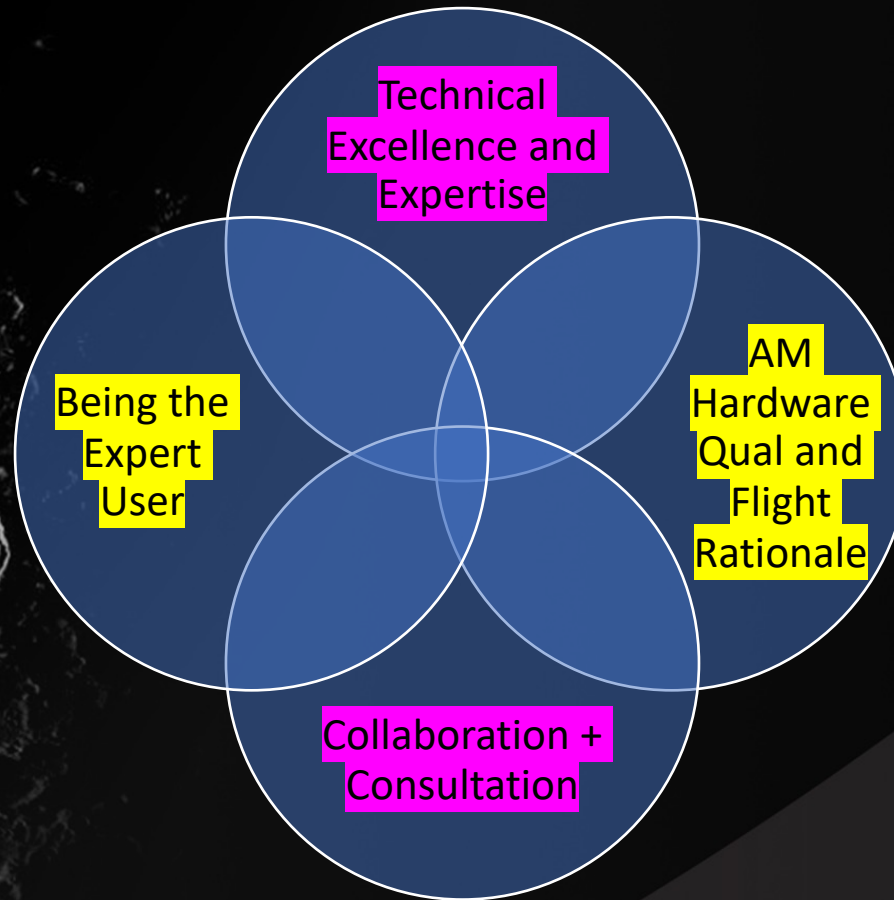
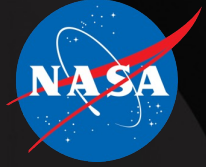
- Transportation from Earth to Destination
- Stations at Destination
- Lander from Station to Surface
- Spacecraft for Science Missions
- Sample Return from Mars

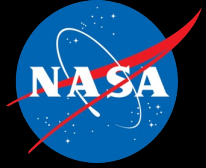
Human exploration of space, especially deep space, requires extreme reliability

What if Apollo Engineers were exposed to AM Techs

- AM could have been a big help to them in design/fail/fix, especially in Rocket Propulsion; but the physics of rocket engine is still a challenge
- Importance in doing groundwork, getting processes in control, critical integration
- Takes a lot of resources from designing, manufacturing and assembling PARTS into a COMPLEX system
- AM may come easy, but Space is hard. Let's do better
- What roles should "Today's NASA" play in AM for Space applications

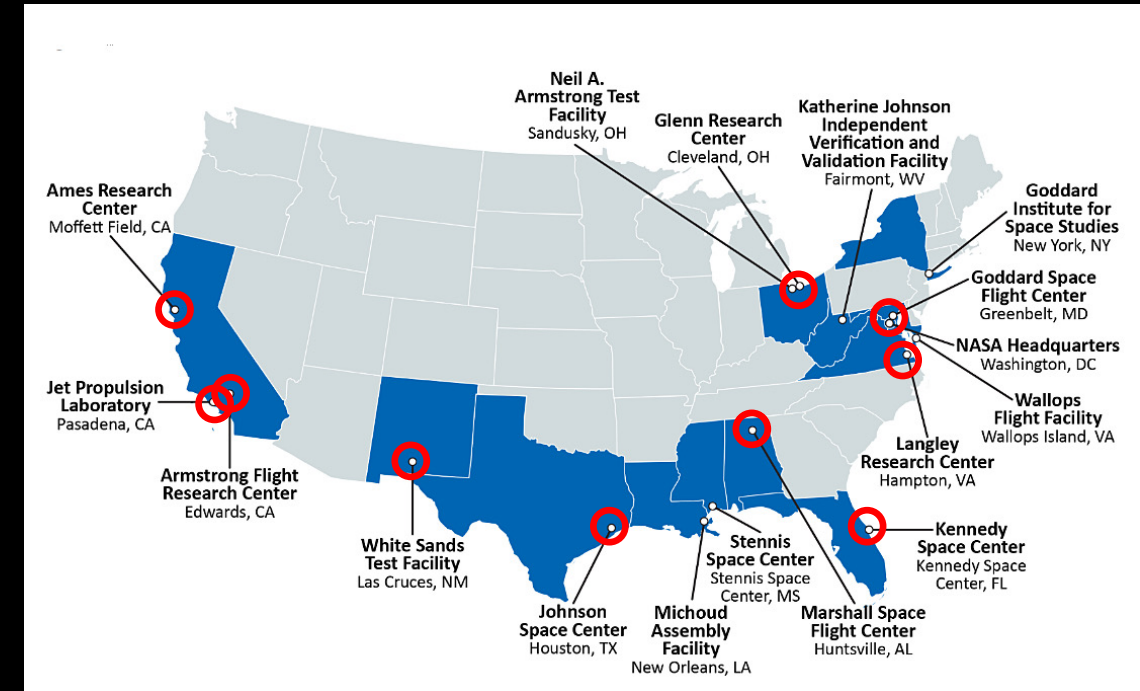
NASA's Roles in Additive Manufacturing



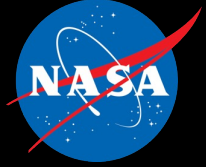


Additive Manufacturing at NASA

- Fully embraces advantages of AM
 - Cost/lead time/part count reduction, new design and performance opportunities, rapid design-fail-fix cycles
- While fully understanding the challenges
 - Especially in delivering high value, high performance AM hardware
- “NASA is an user of AM” means...
 - NASA engineers utilizing AM processes to make hardware = NASA has the design authority
 - NASA procuring sub-system (rocket engine) or system (lunar lander spacecraft) from a commercial vendor/partner = NASA does not have the design authority; vendor does
- End goal → **Safe and successful missions**

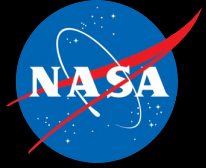


Qualification and Certification – NASA Definition



- Answer varies by industry and even by culture within industries
- The following interpretations are common within NASA:
 - **Qualification** applies to
 - Parts and components
 - Processes
 - **Certification** applies to
 - Design (e.g., status following Design Certification Review)
 - Subsystems (e.g., engine level certification test series)
 - Integrated system (e.g., collective certification for flight for launch vehicle)

Certification is granted by the responsible reviewing authority when the verification process is complete, assuring both design and as-built hardware will meet the established requirements to safely and reliably complete the intended mission.

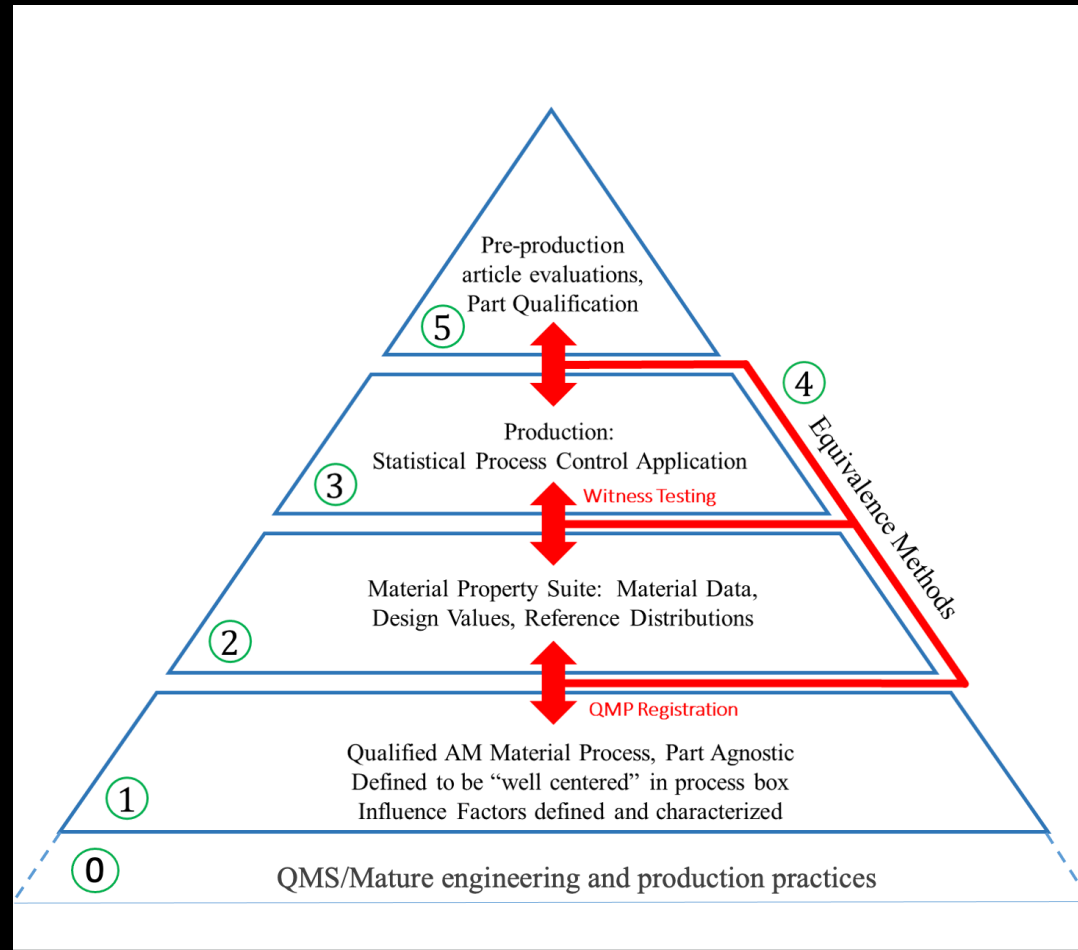
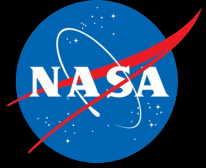


- We have been qualifying flight parts for a long time
- We know how to integrate parts into complex systems

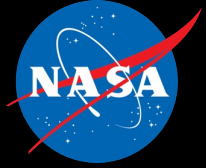
AM Qual is not that special, BUT...

- Individual nature of AM
 - Potential failure modes on a stand-alone operation
 - Process sensitive
- Rapidly evolving tech
 - Lacking in experiences and standards of performance
- Need increased scrutiny on build-to-build material quality + periodic review and confirmation (process control)

NASA Q&C of AM Hardware – Backbone Philosophy

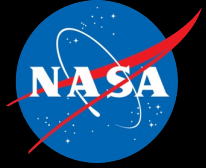


Observations of Current AM Implementations (Space)



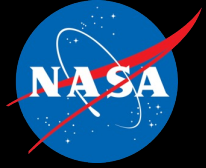
- Highly motivated to print, which places the most complicated of geometries into critical parts/sub systems
- Design/Fail/Fix – empowered by AM
- Going for the Grand Slam
- Process is in place to collect a lot of “data” but not organized enough to utilize the big data
- ***Individual and local aspect of AM – “I’m solely responsible for my material, structure and part integrity”***
 - There is more to AM alloys than bulk chemistry and tensile strength
 - Strength, ductility, fatigue, heat resistance, cryogenic ductility, toughness, tearing resistance, fatigue crack growth, stress rupture, hydrogen embrittlement, oxidizer compatibility, flammability, intergranular cracking, general corrosion, stress corrosion cracking, etc.
 - Just like other traditionally made alloy systems, AM alloys are complex and require precise metallurgical control to meet **engineering expectations** against a variety of failure mechanisms; Process → Structure → Property relationship
- ***The fact that AM parts needs to be successfully integrated into System***

Observations of Current AM Implementations (Space)

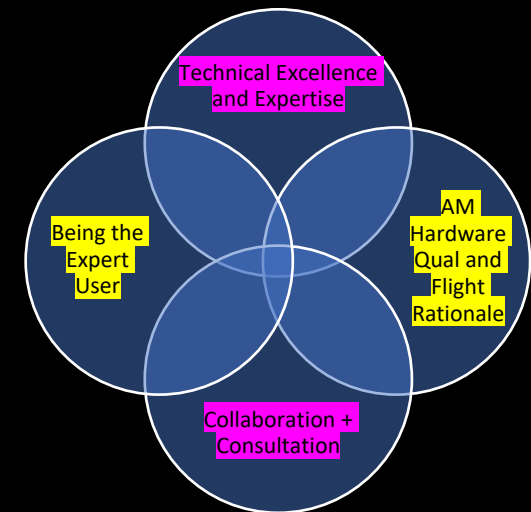


- “AM Qualification is hard” is heard a lot
 - Comes from a realization that it’s not just part qual; it’s also a process qual
 - Do your pre-work right then you will be on a good path for qual
 - Mature your engineering and production practices
 - AM is a small portion of your entire product line value stream
 - Involve everyone as early as possible; especially your friendly Materials Engineers
 - Communicate with your customers and stakeholders to set the right expectations
- Work to set the consistent policy If you were to do post-build inspections for assessing un-inspectable Fracture Critical AM components

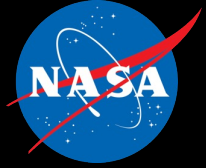
What roles should “Today’s NASA” play in AM for Space applications



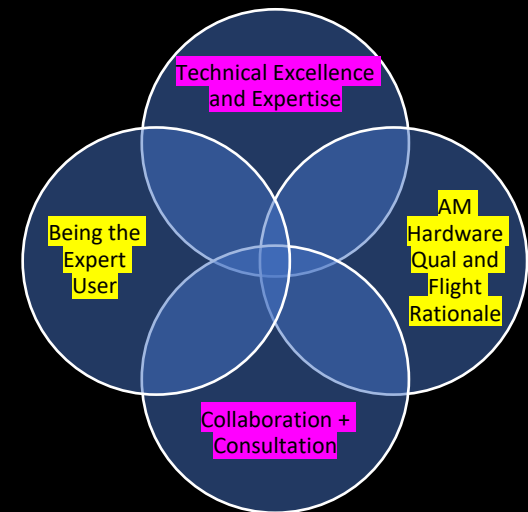
- Technical Excellence and Expertise
 - Propulsion systems and component development enabled by AM
 - Novel Alloy Development – refractory, MEA, OSD, GRCop
 - Extreme environment material characterization
 - Very cold and hot temperature
 - Hypergolic compatibility
 - Flammability
 - Corrosion
- Integrated Computational Materials Engineering
- Damage Tolerance
- Failure Analysis
- “In Space Manufacturing”
- Lunar construction demo



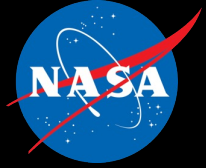
What roles should “Today’s NASA” play in AM for Space applications



- AM Hardware Qual and Flight Cert Rationale
 - NASA-STD-6030 and 6033
 - When these are cited in your NASA program, you get to “sit down” with us to negotiate on the tailored version of 6030 and 6033 to meet the intent of the requirements
 - BUT, we’d like to get to know you earlier than that
 - If you’re from other USG or any other AM policy governing body, let’s chat
- Risks are defined clearly and communicated to Tech Authority



What roles should “Today’s NASA” play in AM for Space applications

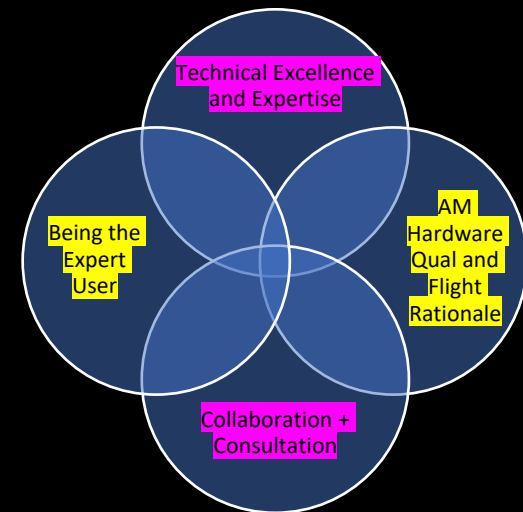


• Collaboration

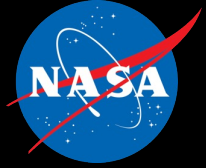
- AM Standard Development Organizations (ASTM, SAE/AMS, MIL-HDBK-5...)
- America Makes, ANSI, NIST, ASTM COE...
- Powder producers, machine makers, software companies, surface treatment, NDE, in-situ monitoring, machining house...
- Academia around the world
- NASA STRI (Space Technology Research Institute) 2023
 - Model-based Qual and Cert for AM

• Consultation

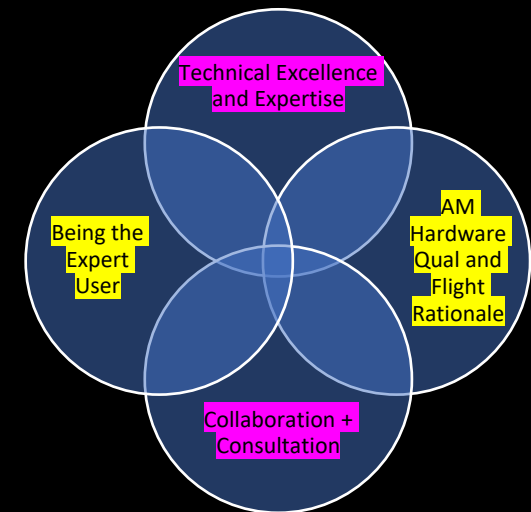
- NASA STMD Tipping Point, CAN, ACO, Space Act Agreement



What roles should “Today’s NASA” play in AM for Space applications



- Being the expert user for in-house applications
 - Robust AM process selection
 - Printer vendor management
 - Design for AM
 - Generative Design
 - Structural Integrity
 - Non-Destructive Evaluation (NDE) Inspection



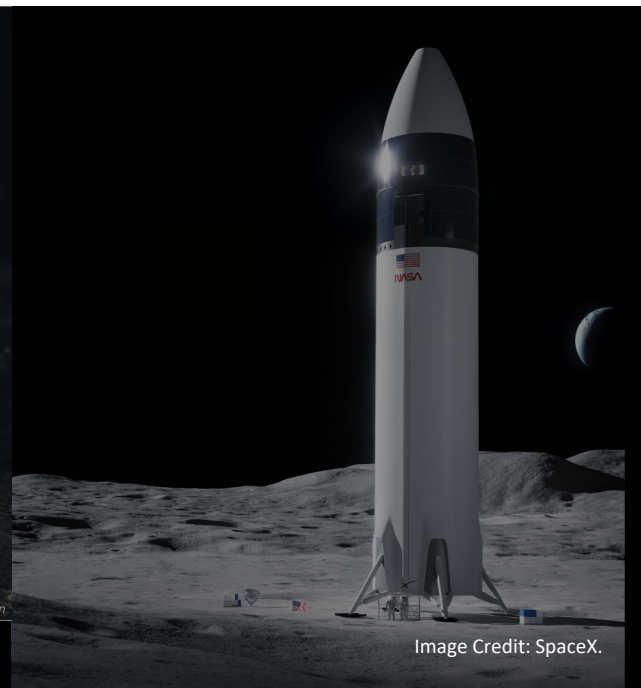


Image Credit: SpaceX.

The most exciting time is now
Artemis Generation bringing excitement
back to space



Image Credit: Blue Origin

